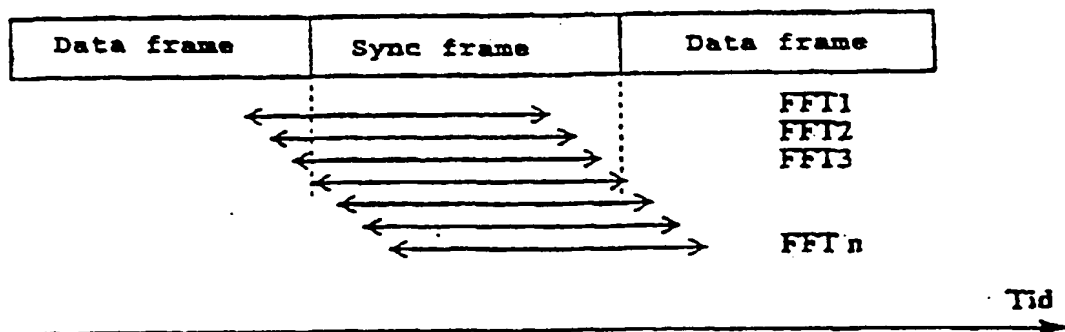


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(21) International Application Number: PCT/SE94/00560 (22) International Filing Date: 9 June 1994 (09.06.94) (30) Priority Data: 9302453-7 20 July 1993 (20.07.93) SE (71) Applicant (for all designated States except US): TELLIA AB [SE/SE]; S-123 86 Farsta (SE). (72) Inventors; and (75) Inventors/Applicants (for US only): ISAKSSON, Mikael [SE/SE]; Borgmästarevägen 7, S-973 42 Luleå (SE). ENGSTRÖM, Bo [SE/SE]; Blidvägen 189, S-951 37 Luleå (SE). (74) Agent: KARLSSON, Berne; Telia Research AB, Rudsjöterrassen 2, S-136 80 Haninge (SE).		(81) Designated States: US, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE). Published <i>With international search report. Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i>

(54) Title: METHOD AND APPARATUS FOR SYNCHRONIZATION IN DIGITAL TRANSMISSION SYSTEMS OF THE OFDM TYPE**(57) Abstract**

The invention relates to a method and apparatus for synchronization of transmitters and receivers in digital transmission systems of the OFDM type. The system uses FFT technique to carry out the modulation and demodulation procedures. According to the invention, the transmitter sends synchronization frames with known frequencies and phase positions and with known time intervals in certain time slots. The receiver carries out a series of time-shifted FFT operations over the time position where the synchronization frame is calculated to be. For each operation, a cross-correlation is carried out in the frequency plane of the output signal with the known frequency function of the synchronization frame. The correlation maximum is detected, and this determines the time slot which contains the synchronization frame, whereupon this is used as time base for the following data frames.

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TITLE OF THE INVENTION: METHOD AND APPARATUS FOR
Synchronization IN DIGITAL TRANSMISSION SYSTEMS OF THE
5 OFDM TYPE

FIELD OF THE INVENTION

The present invention relates to a method and apparatus
to determine synchronization parameters for time shift,
phase turning and frequency drift in a broad-band digital
10 transmission system of the OFDM type (Orthogonal
Frequency Division Multiplexing). The technique which is
used is that certain time slots have known
synchronization frames containing tones or subcarriers in
the whole frequency spectrum with known phase selected in
15 accordance with a pseudo-random pattern (PRBS-sequences).

The receiver carries out a series of time-shifted FFT
operations over the time position where the
synchronization frame is calculated to be. For each FFT
operation a cross-correlation is carried out in the
20 frequency plane of the output signal with the known
frequency function of the synchronization frame. The
cross-correlation means that a very well-defined
correlation maximum is only obtained when the FFT
operation is carried out in exactly the correct time
25 slot. The phase for the cross-correlation maximum shows
clearly on the synchronization frame phase and is used
for phase correction during demodulation of data. The
frequency deviation which is used when regulating this
can be calculated from the cross-correlation. The
30 frequency error is obtained by reading off the position
of the cross-correlation maximum in the correlation
sequence.

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The apparatus is provided with RAM memory, FFT processors and digital signal processors (DSP).

STATE OF THE ART

5 It is already known to use correlation calculations between a known and a received sequence in the frequency plane.

10 US-A-4 577 334 shows a receiver for digital data modulated on a carrier wave signal. At the beginning of a data transmission, a training sequence with a known frequency is transmitted. The receiver contains circuits for determining certain parameters such as the phase between the transmitted training sequence and a corresponding sequence generated in the receiver. The receiver uses a DFT (Discrete Fourier Transform) filter
15 to determine the correlation between the input signal and a locally generated frequency.

20 US-A-4 754 449 describes a receiver which, using a Fourier transformer, receives a number of FDMA channels and transforms these into a single TDM channel. Any phase error in the incoming information is detected by allowing a symbol window to sweep forwards and backwards over the incoming symbols. An error signal is generated if a time shift is detected for an individual symbol compared to previous transmissions.

25 US-A-4 701 939 relates to a method and equipment for obtaining synchronization between a transmitter and a receiver. Synchronization sequences are transmitted in the form of pseudo-random patterns. The received synchronization sequences are compared by an auto-correlation
30 technique with known sequences, and in this way synchronization between the transmitter and receiver can be obtained.

US-A-5 148 451 concerns a device for synchronizing a

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mobile unit with an incoming carrier wave. The incoming carrier wave is modulated with data and a unique sequence. This unique sequence is periodically incorporated in the data information in each frame. The
5 unique sequence is also stored locally in the mobile units. A circuit performs a cross-correlation between the modulated unique sequence and the stored sequence. The result of the cross-correlation is used for frame and carrier wave synchronization.

10 It is, however, not known to perform time-shifted FFT operations and cross-correlate the result in the frequency plane and to use such synchronization methods in OFDM networks.

BRIEF DESCRIPTION OF THE DIAGRAMS

15 The invention will now be described in detail with reference to the attached diagrams, of which
Fig. 1 is a block diagram of the transmitter and the receiver in an OFDM system,
Fig. 2 shows the insertion of synchronization frames in
20 accordance with the present invention,
Fig. 3 shows a diagram of the detection of a synchronization frame, and
Fig. 4 is a block diagram of the synchronization part in the receiver in accordance with the present invention.

25 DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

In order to make it easier to understand the invention we will first present a brief general description of the modulation method OFDM and its characteristics.

30 By OFDM is meant Orthogonal Frequency Division Multiplexing. The basic idea of OFDM modulation is that the data to be transmitted is divided up into a large number (N) of modulated subcarriers so that each of the subcarriers is given a low bit speed. The reason for this is

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to counteract the effects of frequency-selective fading which causes inter-symbol interference. By using a large number of frequency-divided channels where each one has a symbol time which is considerably longer than the length of the channel's time dispersion, the effect of this problem is reduced. In frequency-selective fading, different parts of the frequency spectrum are damped greatly in different ways, resulting in dips in the frequency band. For OFDM-modulation this means that certain subcarrier channels can be completely or partly extinguished, which means that the information from these is lost. This information can be regained by channel coding. The modulation method using combined OFDM and channel coding is usually called COFDM (Coded OFDM).

What distinguishes conventional frequency-division modulation from OFDM is that the frequency spectrum of the adjacent subcarriers overlaps, which gives an optimal frequency utilization. This can be carried out by the signals having orthogonal characteristics which make it possible to modulate each channel so that the neighbouring channels are not disturbed. An attractive feature of this is that the modulation and demodulation processes can be carried out using FFT technique (Fast Fourier Transform).

Fig. 1 shows a block diagram of the transmitter and the receiver in an OFDM system. Inverse FFT is carried out in the transmitter on a block of N symbols. The symbols before the IFFT operation can be regarded as frequency functions for each subcarrier and can be given any modulation form. The time function of the symbols is transmitted over the channel, and FFT of this is carried out in the receiver before demodulation of the data.

The present invention provides a method for synchronizing OFDM systems of the above type. The method is based on inserting known synchronization frames in time. The synchronization frames frame a number N of data frames

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which form a block, as shown in Fig. 2.

The purpose of the synchronization frames is to make it possible, via digital signal processing in the receiver, to estimate a time reference for sampling of data. In addition the signal processing permits the estimation of the phase turning the channel has given the synchronization frame and an estimate of the frequency drift. These parameters are then used in the detection of subsequent data frames. The concept is based on assuming that the channel is approximately stationary (time invariant) between the synchronization frames so that the parameters estimated can be used in the detection of subsequent data frames. The synchronization frames are repeated at known intervals which are selected based on the channel's rate of change, ie the rate the parameters vary, and on the calculation capacity which is required to estimate the synchronization parameters.

The synchronization frame is designed for processing in the frequency plane through FFT technique and cross-correlation. It is of the utmost importance that the whole frequency spectrum is used in order to give robustness against frequency-selective fading.

The frame consists of known frequencies with known phase positions. The frequencies are divided by number and frequency separation in such a way that during the FFT operation in the receiver the same number of samples are taken as the number of points in the FFT. The frequencies are selected with such separation that they lie exactly in frequency for each point in the FFT. The phase position for each frequency is selected in accordance with a PRBS pattern (Pseudo Random Binary Sequence) consisting of -1 and 1. For example, so-called M sequences can be used as PRBS sequence. The choice of PRBS sequences is to be based on the auto-correlation characteristics and is one of the cornerstones of the synchronization method.

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The synchronization frame is generated by inverse FFT (IFFT) in the transmitter. According to the invention the synchronization frame is generated by generating frequencies (tones) in the frequency plane with predetermined phase, calculating IFFT, and transmitting the time function of the operation in the time slots concerned between the data frames. Since the synchronization frame is known and repeated continuously, the IFFT operation can be carried out in advance and stored in EPROM. This stored time function of the synchronization frame can thereby be transmitted by direct reading from EPROM in the predetermined time slots.

The receiver has a measure on time position and phase for the previous synchronization frame. On account of distortion of the channel and shortcomings in the transmitter and receiver, these parameters must be updated for each new block of data frames. To update these parameters the previous time position is used to find the new one by carrying out a series of FFT operations.

As shown in Fig. 3, first more samples are taken than the FFT length over the area where the synchronization frame is calculated to be in time. A series of FFT operations overlapping in time, sliding FFT, is carried out on these samples, in order to find the position of the time slot where the synchronization frame is situated.

After each FFT operation, cross-correlation is carried out against the known frequency function of the synchronization frame. Since the phase of the respective frequency was selected as PRBS sequences, the cross-correlation will give a very well-defined amplitude maximum only in the time slot which contains the synchronization frame. This cross-correlation maximum is detected for each time shift of the signal, and at the time shift where the greatest (only) maximum is obtained this is used as the time base for the subsequent data.

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The phase for the cross-correlation maximum shows clearly the phase of the synchronization frame and is used for phase compensation when detecting the subsequent data.

5 The cross-correlation also provides information on frequency deviations. These deviations usually arise as a result of deviations between the oscillators of the transmitter and receiver, but can also arise as a result of Doppler effects in mobile systems. The frequency error appears by the amplitude maximum in the cross-
10 correlation varying around the midpoint in the sequence (maximum in the midpoint - no frequency error). If the amplitude maximum is moved one step in the sequence it corresponds to a frequency drift on an FFT-point's resolution frequency separation.

15 Another characteristic of the method is that the phase deviation and amplitude for various frequencies in different parts of the frequency spectrum can be read off directly from the FFT for the synchronization sequence which can be used for channel estimation in the
20 event of frequency-selective fading.

Fig. 4 shows a block diagram of the synchronization component in the receiver in accordance with the present invention.

25 The receiver consists of a sampling unit, direct memory (RAM), FFT processors and digital signal processors (DSP).

The sampling unit digitizes the signal by sampling and buffers this in the RAM memory (complex signal). The RAM memory acts as buffer for a sufficient quantity of data
30 of the signal so that the time reference for data detection is able to be given as an address-offset to this memory (circular buffer).

There are two FFT processors in the receiver. One FFT

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processor is for detecting data and the other FFT processor is for detecting synchronization parameters. The result of the operation from the FFT processor used for synchronization is read in by DSP units and
5 processed for estimating the synchronization parameters.

The parameter for time synchronization is given to the address handler for the FFT processor for data detection as an address-offset to the RAM memory, ie where this is to begin to read in the data.

10 The estimated parameter for phase turning is given to the demodulation unit after the FFT processor. This unit demodulates each subcarrier channel and corrects phase and amplitude.

The frequency drift which is measured is used by a
15 frequency regulating unit which is not part of the invention. Frequency regulation can be carried out in various ways. One way is to control numerically controlled oscillators (NCO) by mixing and to feed back the result to the regulator. Another way is to
20 compensate for the frequency drift digitally before the FFT operation in the receiver with similar feed-back.

An FFT processor is a signal processor optimized for vectorial operations on large data quantities, such as FFT, correlation and FIR filtering. This type of
25 processor is considerably quicker than general signal processors for these types of operation.

The FFT processor is adapted for carrying out the operations in the frequency plane. By this is meant that the architecture is optimized for carrying out FFT (Fast
30 Fourier Transform) on incoming data. After the FFT operation, filtering and correlation, etc, can be carried out in the frequency plane as vectorial multiplying by the frequency function of the transmission function. The FFT processor has a memory structure which is so

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constructed that what is known as ping-pong technique can be used. By this is meant that data is read from one RAM memory, processed in the FFT processor and stored in the second RAM memory. The parameters or coefficients which are used for each operation are stored in a special RAM memory.

In the synchronization method in accordance with the invention the FFT processor is used for sliding cross-correlation in the frequency plane against the received synchronization frame. A general arrangement for the operations for the FFT processor can be described by the following pseudo code:

```
for j=(tau_old-k) to (tau_old+k) do
    f=FFT(s(j to j+fft_len-1))
    c=corr(f_sync,f)
    save_to_DSP(c)
end
```

A correlation in the frequency plane can be carried out by multiplying the data by the time function of the synchronization frame in the time plane before the FFT operation. This method is considerably more efficient than carrying out the operation by a correction after the FFT operation and is therefore used in this invention. An advantage of this procedure is that the FFT processor supports this operation, which it does not do for a pure correction. The pseudo code can thereby be modified for this synchronization method by:

```
for j=(tau_old-k) to (tau_old+k) do
    sm=conjugate(t_sync)*s(j to j+fft_len-1)
    c=FFT(sm)
    save_to_DSP(c)
end
```

The operations which the FFT processor carries out are then as follows in descriptive text:

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1. Read in the input signal sample from the previous time base τ_{old} . From $\tau_{old}-k$ to $(\tau_{old}+k-fft_len)$ the input signal sample is stored in the RAM memory. The factor k is selected dependent upon the maximal time shift which is calculated and upon how often this is updated. The calculating capacity which is available is also decisive.
2. For each time shift of the stored input signal, multiplication by the time function of the synchronization frame is carried out. This is stored in a bank in the coefficient RAM memory. After multiplication, FFT is carried out on the result, giving the cross-correlation in the frequency plane. The cross-correlation is stored for further processing by DSP.
3. When all operations above have been carried out for all time shifts of the signal and the new time base, τ_{new} , has been estimated, a further FFT operation is carried out for the new time base. This operation is carried out without frequency correlation and is to estimate the channel's distortion of the synchronization frame. This gives values for phase and amplitude distortion for the whole frequency spectrum, which permits compensation when demodulating data.

It is of the greatest importance to minimize the load on the DSP processor for broad-band signal processing since this is to the power ten slower than FFT processors in calculating capacity. However, a DSP processor has a considerably greater instruction set than a vector processor and can therefore perform operations which are more or less impossible with a vector processor. Examples of such operations are scalar operations such as comparisons, bit manipulation, memory operations and the ability to construct large complex program structures.

In accordance with the invention, the DSP processors have

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the task of reading in the correlation sequences which are obtained from the FFT processor. From these correlation sequences, the DSP can find the correlation maximum and calculate its time base and phase turning.

5 The time base is used for controlling the sampling of data to the FFT processor for data demodulation. The phase turning is supplied to the demodulating unit after the FFT processor where phase compensation and correction take place.

10 After this, the frequency drift is estimated by processing the correlation sequence's selected time base. This parameter is used by the unit for frequency regulation.

15 The DSP also processes the channel estimate which is obtained from the FFT operation for the correct time base and supplies this to the demodulation unit.

In this way the present invention provides a method and apparatus for synchronization of an OFDM system.

20 The invention has the following advantages compared with previously known techniques:

- The synchronization is based on the whole frequency spectrum.

- The transmitter and receiver in an OFDM modem operate in the frequency domain. According to the invention, all
25 synchronization parameters in the frequency domain are estimated, which gives a similar hardware architecture to that for demodulation of data.

- OFDM modulation by FFT technique automatically gives a high level of controllability of discrete frequencies
30 and their phase position.

- The method gives a relatively high proportion of

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synchronization parameters from the same operations: time shift, phase turning, frequency drift and channel estimating.

- 5 - The method includes acquisition, ie finding the abovementioned initial parameters for the subsequent data, but provides a good basis for tracking (phase compensation, frequency regulation and channel correction during demodulation).
- 10 - An accurate estimate of frequency drift gives high potential for digital frequency regulation. By this is meant that if the limits of the frequency error are known, ie lie within a known interval, instead of regulation via analog components (numerically controlled oscillators, etc) regulation of the sampled signal can
15 be carried out digitally.
- 20 - Instead of inserting special synchronization frames, what are known as "guard spaces" in the data frames can be used as synchronization frames. This means that no degradation of transmission capacity is required for the synchronization. However, during synchronization the
25 synchronization frame must be sampled at the same rate as the data frame and a shorter FFT carried out (type 1/8 data FFT) on this, which gives a worse resolution in frequency and correlation. This has, however, the advantage that the FFT operation is carried out much more quickly.

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PATENT CLAIMS

1. Method for synchronization of transmitter and receiver in digital transmission systems of the OFDM type which uses FFT technique to carry out the modulation and demodulation process, characterized in that synchronization frames with known frequencies and phase positions are sent at known intervals by the transmitter, in that a series of time-shifted FFT operations are carried out by the receiver, in that the receiver carries out cross-correlation against the known frequency function after each FFT operation, in that the correlation maximum is detected, which determines the time slot which contains the synchronization frame, whereupon this is used as time base for the subsequent data frames.

2. Method according to Claim 1, characterized in that the phase position for the respective synchronization frame's frequency is selected in accordance with a random pattern (PRBS).

3. Method according to Claim 1 or 2, characterized in that the respective synchronization frame is generated by generating frequencies in the frequency plane with predetermined phase, calculating the inverse Fourier transform (IFFT) of this and transmitting the time function of the operation in predetermined time slots between the data frames.

4. Method according to Claim 3, characterized in that the IFFT operation is stored in advance in an EPROM, the synchronization frame being able to be transmitted by direct reading from the EPROM in the predetermined time slots.

5. Method according to any of the preceding claims, characterized in that the series of time-shifted FFT operations is carried out by first sampling more samples

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than the FFT length over the area where the synchronization frame is calculated to be in time, and in that a series of FFT operations overlapping in time is carried out on the sample.

5 6. Apparatus for synchronization in digital transmission
systems of the OFDM type which utilizes FFT technique to
carry out the modulation and demodulation procedures in
order to carry out the method upon receiving a signal in
accordance with any of the preceding claims, charac-
10 terized by a sampling unit for digitization of the
signal by sampling, direct memory (RAM) for storing a
sufficient quantity of samples of the signal, an FFT
processor for detection of data, an FFT processor for
detection of synchronization parameters by means of
15 cross-correlation in the frequency plane, a digital
signal processor (DSP) for reading in correlation
sequences and from these detecting the correlation
maximum and calculating the required time base.

20 7. Apparatus according to Claim 6, characterized in that
the FFT processors are signal processors optimized for
vectorial operations on large quantities of data.

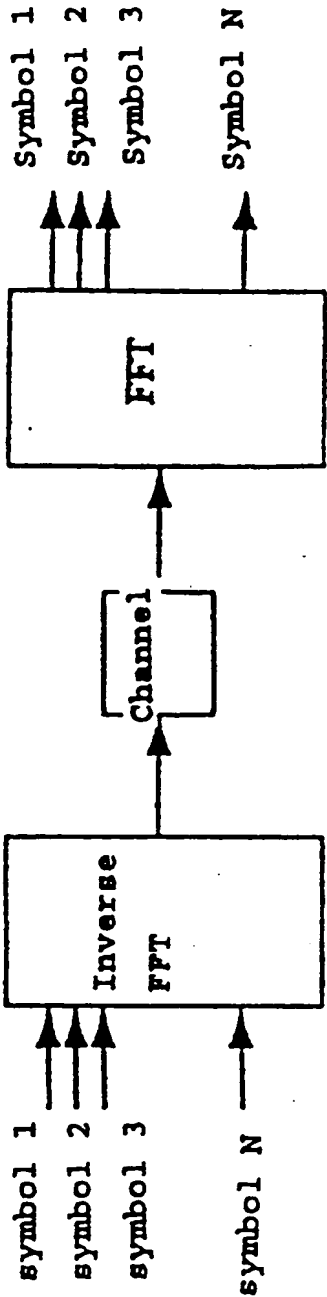


FIG 1

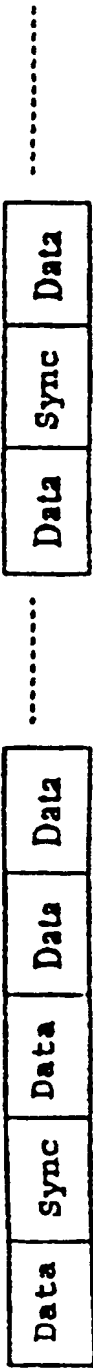


FIG 2

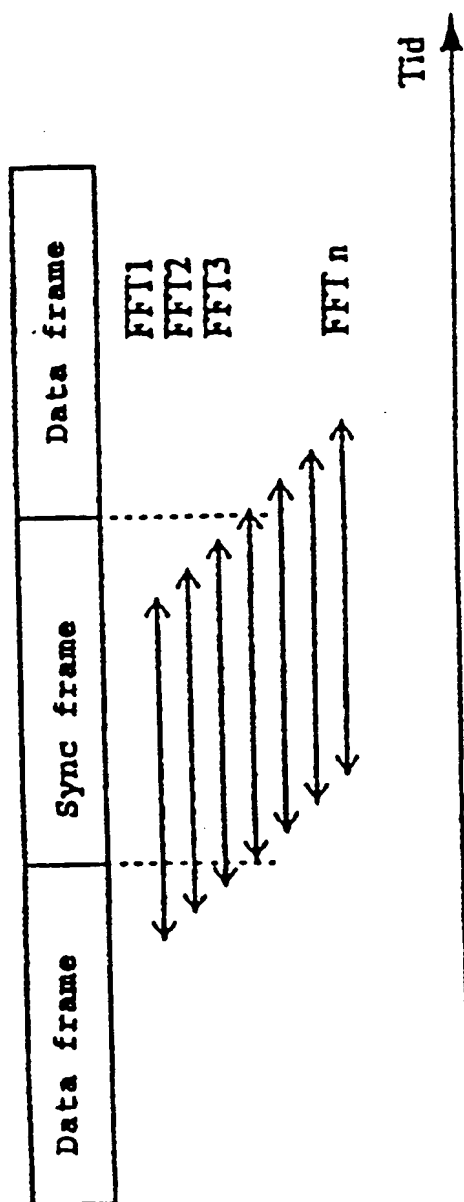


FIG 3

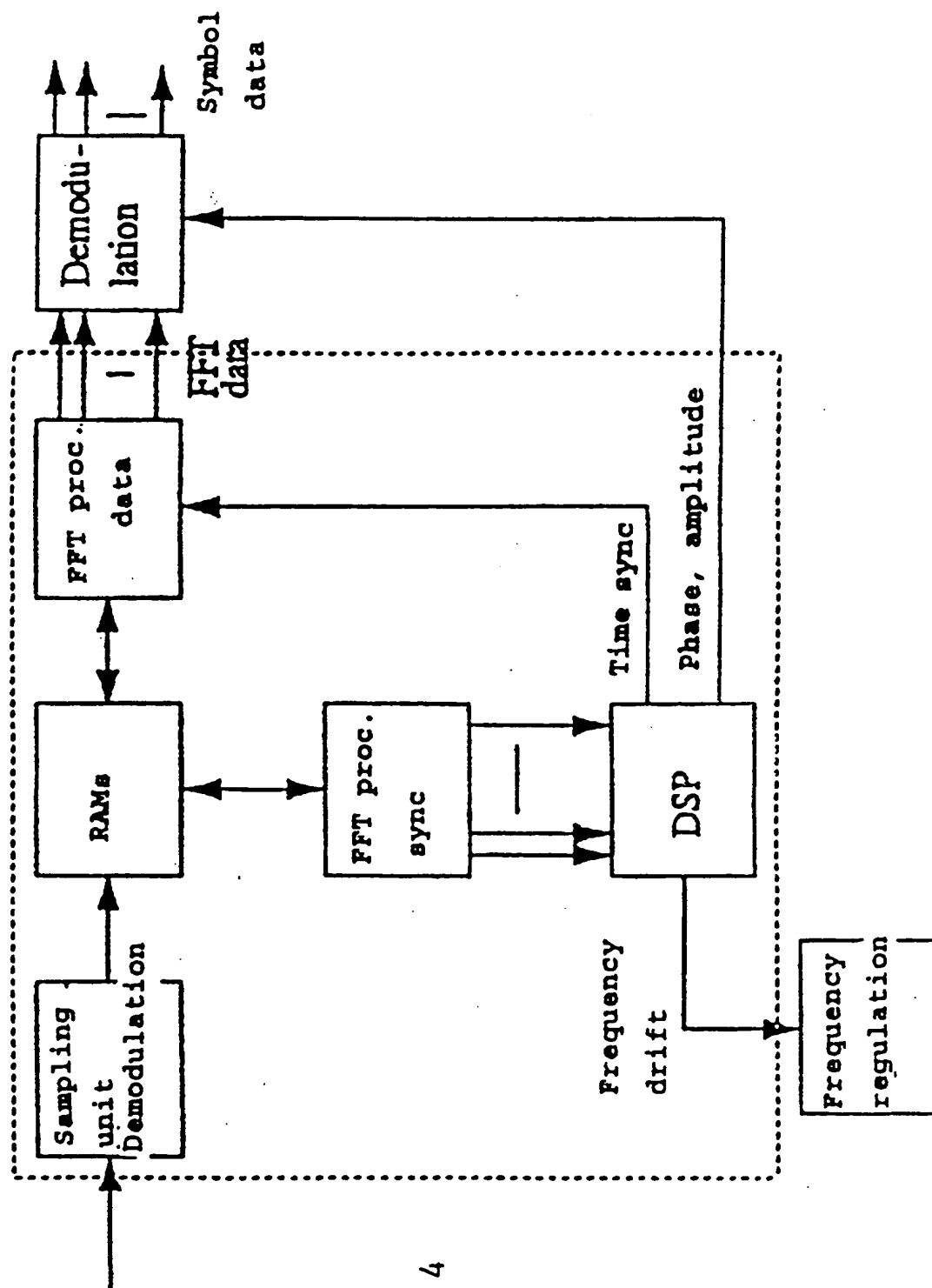


FIG 4

INTERNATIONAL SEARCH REPORT

International application No.

PCT/SE 94/00560

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H04L 5/06, H04L 7/08

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: H04L, H04J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

CLAIMS, WPI, PAJ, EPODOC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P,A	EP, A2, 0556807 (NEC CORPORATION), 25 August 1993 (25.08.93), see the whole document --	1-7
A	US, A, 5148451 (SUSUMU OTANI ET AL.), 15 Sept 1992 (15.09.92), see the whole document --	1-7
A	WO, A1, 9210043 (THOMSON-CSF), 11 June 1992 (11.06.92), abstract -- -----	1-7

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Date of the actual completion of the international search

25 November 1994

Date of mailing of the international search report

28 -11- 1994

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INTERNATIONAL SEARCH REPORT

Information on patent family members

29/10/94

International application No.

PCT/SE 94/00560

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP-A2- 0556807	25/08/93	AU-A- 3313793 JP-A- 5227235	19/08/93 03/09/93
US-A- 5148451	15/09/92	AU-B- 627380 AU-A- 6655090 CA-A, C- 2029675 EP-A- 0427283 JP-A- 3153145	20/08/92 16/05/91 11/05/91 15/05/91 01/07/91
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